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DITCH MAINTENANCE EXPERIMENTS IN OHIO AND DELAWARE

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For information of the engineers of the
C.C.C. drainage camps

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Contents

	Page
Introduction	3
Scope of experiments	4
Acknowledgment of cooperation	5
Use of dynamite for cleaning ditches	5
Experiments in Ohio	6
Experiments in Delaware	8
Methods of detonating	13
Limitations in use of explosives	13
Cleaning channels with hand labor	14
Cleaning channels with teams and scrapers	15
Cleaning channels with double-drum hoist and scoops	15
Cleaning channels with dragline excavators	16
Prevention of channel and bank erosion	17
Control of vegetation	18
Summary and conclusions	19

INTRODUCTION

The 1930 report of the Bureau of the Census shows 84,408,093 acres drained in 35 States with 138,673 miles of ditches. The best authorities estimate that from $1,500,000,000 to $2,000,000,000 have been spent by drainage enterprises and private individuals on these drainage improvements. The security of this investment is entirely dependent on the condition of the outlet ditches. The Census report shows the inadequacy of present maintenance provisions. Of the 84,408,093 acres reported, only 11,619,679 acres are in drainage districts owning equipment for maintenance purposes. The remaining 72,788,414 acres are drained by channels either maintained by hand labor, or by a hit-and-miss system of letting the work by contract after drainage conditions have become intolerable.

In most drainage districts, effective measures have not been taken to provide adequate maintenance of the constructed improvements. The activity of drainage boards has usually almost ceased after the completion of the original construction program. Unless favorable conditions exist which render the channels self maintaining, deterioration begins soon after excavation. The formation of a few deposits, easily cleared away if attended to early, may, if neglected, make reconstruction of the entire channel necessary within a period of a few years. The adoption of an adequate annual maintenance program immediately following construction and persistance in carrying out that program have generally proven to be the most satisfactory and economical method of keeping a drainage system in a proper state of efficiency.

Most of the bond issues for construction purposes were for 15 and 20 year periods. Without maintenance, this is usually much longer than the effective life of the channels, which is normally 5 to 8 years. As a result of this practice, farmers have been attempting to pay for drainage systems long after they have ceased to function effectively. The lowest lands on the projects have been assessed the heaviest, assuming these benefit most from drainage improvement. Without maintenance, these lowest areas are the first to suffer crop losses due to inadequate drainage, and the improvement made is often so short-lived that benefits assessed far exceed those actually conferred. When the lands most heavily assessed are nonproductive and unable to pay, both landowners and bondholders are likely to suffer losses. The only correction for these faults is to insure continuous and adequate drainage through an efficient and practical program of ditch maintenance.

The failure of drainage systems to function satisfactorily, due either to excessive maintenance cost or to no maintenance at all, has created a widespread demand for more definite information on efficient and effective maintenance practices.

Since the dredge was introduced, about 1885, continuous improvements have been made in developing larger and more efficient excavating equipment suitable for constructing ditches at low cost, but less progress has been made towards developing a machine economical for light maintenance work. One reason for this is the absence of a strong demand for such equipment. There has been a notable lack of scientific data available on maintenance of drainage ditches, which has added to the uncertainty regarding proper practices to follow and the funds that should be set aside for annual improvements.

Scope of Experiments

The first experiments in drainage maintenance conducted by the Bureau of Agricultural Engineering related to the use of explosives in cleaning ditches. There were made in Wood County, Ohio in 1930 in cooperation with the extension department of Ohio State University and with a manufacturer of explosives.

In 1931 the State legislature of Delaware appropriated $10,000 annually for two years to be used by the State Highway Department in maintaining drainage ditches in Kent County. In September of that year the U. S. Bureau of Agricultural Engineering signed a cooperative agreement with the State Highway Department to conduct experiments to develop better maintenance practices and to determine costs of cleaning channels by some of the methods now in use.

The plan for conducting the experiments in Kent County was to improve only the main channels and to spread the work to benefit all sections of the county equally. This program, while not in any way indicating the needs and costs of annual maintenance of well constructed channels, does show costs of cleaning out various amounts of material per rod of ditch by methods now in use. In this work approximately 18 miles of ditches were repaired and from 90,000 to 100,000 cubic yards of soil were excavated.

A survey was made of each ditch and grade was established before the cleaning work was started. Dynamite, hand labor, teams and scrapers, a tractor with mounted hoist and scoops, and a dredge were all used in the Delaware experiments. On one ditch sodium chlorate was applied to kill a dense growth of briars in the channel. Costs of the various phases of the work were recorded and these data comprise the body of this report.

The ditches selected for cleaning or other maintenance work were found to be in a most unsatisfactory state of repair. Most of them had been only slightly repaired by landowners each year. On some channels $100 to $150 per mile had been spent annually. However, this work consisted almost entirely of labor, often supervised by inexperienced men and without the assistance of surveys to determine grades. In most cases capacities of the ditches had been reduced to less than one-third of that

required for proper agricultural drainage. Grades were very irregular, and obstructions almost completely filling the channels were frequent. Many fence lines were continued through the ditches, with posts set in the channels and these collected so much debris that little water could pass. Sharp curves, resulting in heavy erosion, were numerous. In many sections briars and trees growing within the channels almost completely obstructed flow during the growing seasons. Where the channels passed through timbered sections trees 2 to 3 feet in diameter were buried in the ditch bottoms.

A comparatively flat topography has greatly minimized the need for maintenance work in Kent County, Delaware. The most intense rainfalls cause little surface erosion and only small amounts of silt and debris are washed into the channels. However, long neglect had made the drainage systems practically useless.

Acknowledgment of Cooperation

The Ohio experiments were conducted in cooperation with the Ohio State University and E. I. du Pont de Nemours & Co., Wilmington, Delaware. Virgil L. Overholt, Extension Specialist, represented the Ohio State University in planning and conducting the experimental work.

The Delaware experiments were conducted in cooperation with the Delaware State Highway Department. Acknowledgment is made of the cooperation and advice given by W. W. Mack, Chief of the Highway Department, and W. A. McWilliams, Resident Engineer for the Highway Department.

USE OF DYNAMITE FOR CLEANING DITCHES

Dynamite was first used in ditching work about 1897. At that time and for many years since, it was considered an emergency method, to be used only when a bypass for flood waters or other channels was needed immediately. The principal reason for its restricted use was a general lack of knowledge as to correct methods of using and handling high explosives. In recent years both materials and methods of using dynamite have been improved and it is now being assigned a definite place in ditching work where conditions make its use economical. For favorable conditions, the soil must be well saturated with water and the depth of cut must be sufficient to permit efficient use of the explosives.

The ease with which a large amount of potential power is transported in the form of explosives gives dynamite an advantage over other methods of excavating when transportation of power in the field is a considerable part of the total cost. This condition is found where intermittent bars or widely separated sections of a channel are to be excavated. Excavating equipment may not be available for a small ditch-cleaning job or to remove small and intermittent deposits from a channel, or if available its use may be too expensive. Moving the equipment may comprise a large portion of the expense and make the cost of excavation excessive.

It is for this class of work that dynamite is employed for cleaning ditches. The individual landowner or small district can purchase and use a quantity of dynamite, and do the work at a reasonably low cost and at a convenient time without making a large investment in machinery. Nevertheless, use of dynamite is not always practicable. The presence of buildings, bridges or power lines near the work precludes the use of explosives.

Experiments in Ohio

In the summer of 1930, 18 experimental blasts were made with dynamite in Wood County, Ohio, to determine the cost of excavating by this method to clear drainage channels of silt deposits. All shots were made using 50 percent nitro-glycerine dynamite sticks 1-1/4 inches in diameter and 8 inches long.

All blasts were made by propagation. One of these blasts (No. 7 in table 1) was to move a small sand bar from a large channel; the others, made in three separate channels, were to remove deposits of clay silt supporting growths of vegetation. The greatest variations in results, where like loads were used, seem due to variations in quantity of water moved by the blasts and, where light loads were used, to differences in density of plant roots. The quantities of water moved were estimated and corrections for this factor are shown in column 6 of Table 1.

Experiments 1 to 7.

Experiments 1 to 7 inclusive were with single-stick, cross-section loads. The width of cross-section loads was varied, using 9, 7, 5, 3, and 2 sticks on cross-section lines (fig. 1,A). This variation in load did not appreciably affect excavation costs. Experiment 7 was in sand, and the explosive was not as effective in this blast as it was in the clay silt. For this experiment cross-section loads were 3 feet apart instead of 4 feet as shown in figure 1. Variations in costs per cubic yard of silt excavation as shown in table 1 for experiments 1 to 6 can be largely ascribed to different quantities of water covering the soil. It requires approximately as much work to throw out a cubic yard of water as it does to move a cubic yard of soil from the channel. To avoid wasting dynamite in moving water, the blasting should be done during minimum water stage. Photo 1 is representative of before and after blasting with cross-section loads. Figure 2 shows the tools used for making the hole and placing the charge.

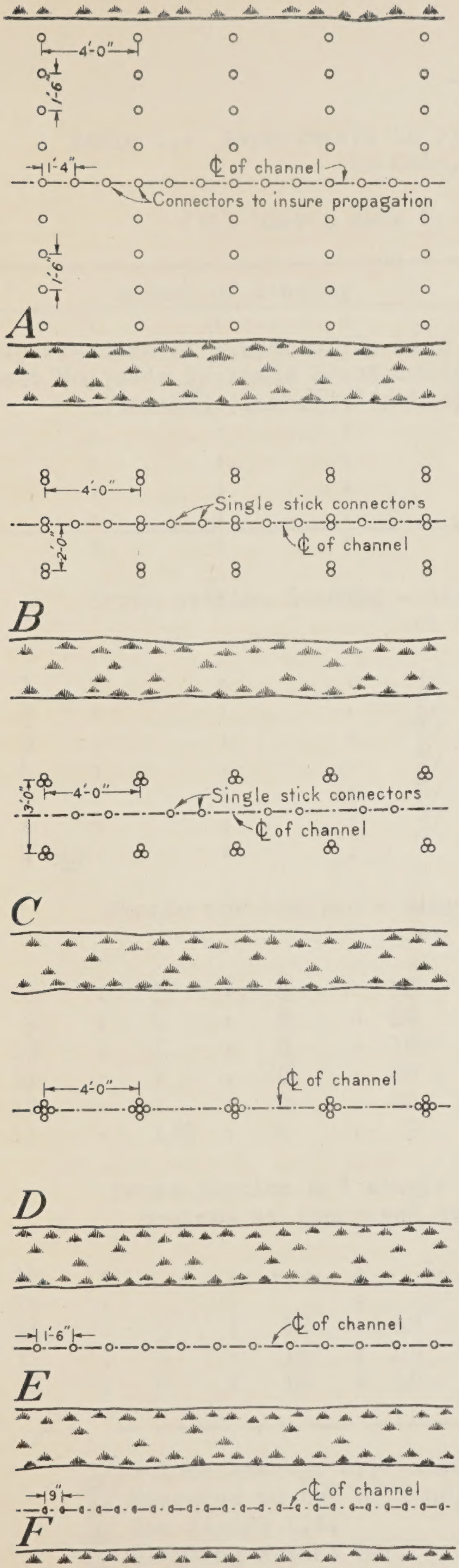


Fig.1.-Loading plans used in ditch cleaning experiments in Ohio

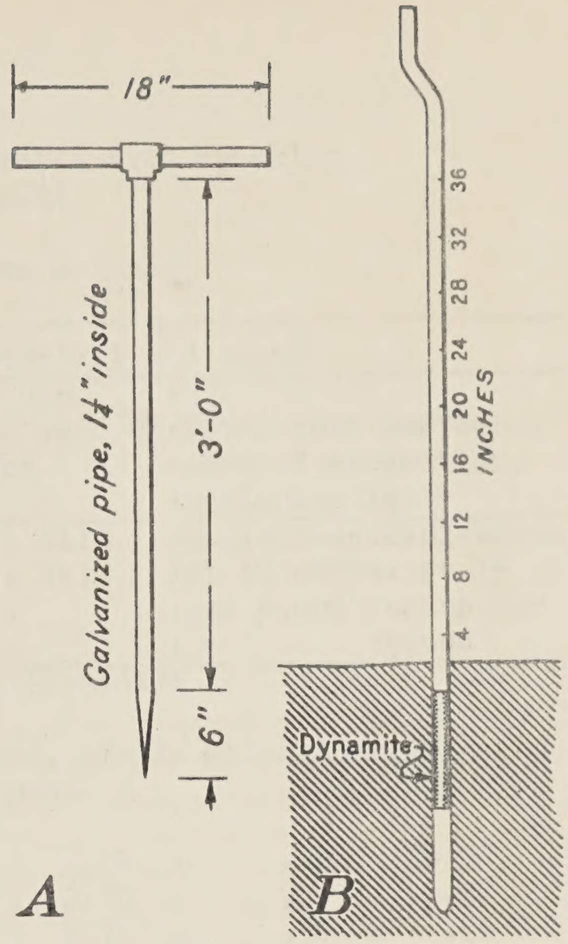


Fig.2.-Tools used for making holes and placing dynamite

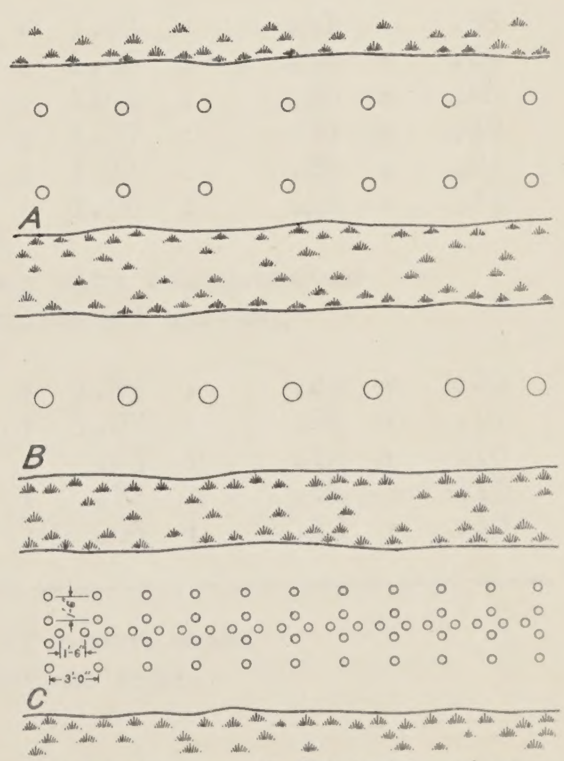


Fig.3.-Loading plans used in ditch cleaning experiments in Delaware

Table 1.- Experiments in cleaning ditches with dynamite in Ohio, in clay soil

(All blasts made by propagation method)

Method of loading				Materials and costs			
Experiment No.	Size of loads 1/ (Sticks)	Depth of loads 2/ (Inches)	Spacing of loads (Inches)	Dynamite used per cubic yard of excavation: Silt plus water moved (Pounds)	Dynamite used per cubic yard of excavation: Silt only (Pounds)	Total cost per cubic yard of excavation, including labor: Explosives at 19 cents per pound	Total cost per cubic yard of excavation, including labor: Explosives at 15 cents per pound
Cross section loading - closely spaced, single stick charges at various depths							
1			3/	1.85	2.18	.45	$0.37
2			3/	1.94	2.22	.47	.38
3			3/	2.08	2.71	.57	.46
4			3/	1.88	2.17	.45	.37
5			3/	1.86	1.95	.41	.33
6			3/	1.85	2.33	.49	.40
7	4/			3.17	3.17	.66	.54
Single row loading - single stick charges at uniform depth at various spacings							
8	1	8	18	1.86	1.93	.41	.33
9	1	8	18	1.68	1.68	.34	.29
10	1	8	18	1.44	1.44	.30	.24
11	1	8	20	1.77	1.77	.37	.30
12	1	8	22	1.33	1.33	.28	.23
13	1/2	6	9	1.90	1.90	.42	.35
Cross section and single row loading with concentrated charges at increased depth and increased spacing							
14			3/	1.23	1.25	.25	.20
15			3/	.98	1.07	.22	.17
16	5	18	48	.59	.63	.12	.10
17	5	18	48	.62	.72	.14	.11
18	5	18	48	.59	.63	.12	.10

1/ Sticks average approximately a half pound each.
2/ Measured to top of load; sticks set on ends.
3/ See figure 1,A.
4/ Blasting a sand bar.

Experiments 8 to 13.

In experiments 8 to 13 inclusive, light single-row loads were used. For experiments, 8, 9 and 10 the loads were identical. Single-stick loads were used in a single row on the center line of the channel. Each stick was set on end with the top 8 inches below the top of over-burden and loads were 18 inches apart (fig. 1,E). In experiments 11 and 12 the same loading plan was used, except that the loads were spaced 20 and 22 inches apart respectively for the two tests. In experiment 13 half-sticks loaded in a single row on the center line of the channel (fig. 1,F). These half-sticks were set only 6 inches below the surface and 9 inches apart. Considerable variation is found in results of these six tests, all made with light, single-row loads. Part of the variation can be attributed to differences in loads, and part to densities of root systems of the vegetative covering. When using a light load of dynamite under a dense sod cover, the material over and very near the dynamite is thrown into the air. Outside the area adjacent to the explosive, the sod cover is rolled back. The density of the root system determines the work required to roll the sod cover away. This will have little or no appreciable effect where heavy loads are used, but where light loads are set near the surface it may be quite noticeable. Photo 2 shows representative sections after blasting with single-stick, single-row loads. Photo 3 shows before and after blasting with 1/2 stick, single-row loads. Photo 4,A shows the blast end/and view photo 4,B the side view in experiment 13, using 1/2 stick loads.

Experiments 14 to 18.

In experiments 14 to 16 inclusive, the load for each successive test was more concentrated (see figs. 1,B; 1,C; and 1,D for loading plans of experiments 14, 15 and 16 respectively). The loads in experiments 17 and 18 were identical with that used in experiment 16. Results of these tests show conclusively that the concentrated load is far more effective in clay silt blasting than are the light, scattered loads. Photo 5 shows channel sections before and after making blasts with the 5-stick, concentrated loads.

Experiments in Delaware

The results of 26 experiments with blasting for ditch maintenance in Delaware are shown in Table 2. All except a very few of the shots were made with 50 percent straight nitroglycerin dynamite in one-half pound sticks 1-1/4 inches in diameter and 8 inches long. A few shots were tried with 40 percent nitroglycerin dynamite. No differences in the effect of the various grades of dynamite could be detected except that with 40 percent dynamite the fire could not be satisfactorily propagated.

All experiments were in sand, and by comparison with the work in northwestern Ohio (table 1) it is evident that dynamite is not nearly as effective in sand as it is in clay or plastic soils. All the work was done in one ditch. The depth of the finished channel varied from 5-1/2 to 6 feet, and the bottom width varied from 12 to 16 feet.

Table 2.- Ditch cleaning experiments with dynamite in Delaware, in sand

Experiment 1/ No.	Method of loading: Size of loads 2/ (Sticks)	Depth of loads 3/ (Inches)	Spacing of loads (Feet)	Materials and costs: Dynamite used per cubic yard of excavation (Pounds)	Total cost per cubic yard of excavation, including labor: Explosives at 19 cents per pound	Explosives at 15 cents per pound
Double row loading						
1 E	3	20	4	3.89	$1.08	$0.93
2 E	3	12	4	2.54	.68	.58
3 E	5	26	5	2.14	.53	.44
4 E	5	16	5	2.85	.62	.55
5 E	9	32	6	3.58	.80	.66
6 E	9	20	6	2.07	.47	.39
Single row loading						
7 E	6	20	4	1.24	.29	.24
8 E	10	26	5	1.70	.37	.30
9 E	18	32	6	2.02	.44	.36
10 E	10	26	6	1.66	.36	.29
11 P	Cross Section loading			2.35	.49	.40
Single row loading, variable depth						
12 P	5	10	3	1.22	.25	.20
13 P	5	16	3	.95	.20	.16
14 P	5	28	3	1.17	.24	.19
15 P	7	16	3	1.44	.29	.23
16 P	7	22	3	1.35	.28	.23
17 P	7	28	3	1.39	.29	.23
18 P	9	16	3	1.72	.35	.28
19 P	9	22	3	1.60	.32	.26
20 P	9	28	3	1.62	.33	.27
Single row loading, variable spacing						
21 P	18	28	6	1.67	.35	.27
22 P	2	22	1	1.69	.38	.31
23 P	3	22	1-1/2	1.34	.29	.24
24 P	4	22	2	1.54	.33	.27
25 P	5	22	2-1/2	1.46	.31	.25
26 P	6	22	3	1.33	.28	.23

1/ "P" shows propagated; "E" shows each load fired by electric cap.
2/ Each stick weighs approximarely 1/2 pound
3/ Measured to top of load; bottom of load 8 inches below this as sticks are set on ends.

A review of table 2 shows a large variation in quantities of dynamite used per unit of excavation. These tests were in uniform soils and the variations in results can be ascribed chiefly to different methods of loading employed. These variations clearly emphasize the need for experimental data on a particular type of soil or class of work before dynamite can be used most effectively in ditching work.

In these experiments tests were made to compare results of single-row, double-row, and cross-section blasting (fig. 3). After the single-row was found most efficient, further tests were made to determine proper space-depth relationships for the various sizes of loads used. While sizes of loads and spacings were left constant, the depths were varied. After this series of experiments was completed, the depths of loads were made constant while load sizes and spacings were varied.

In the experimental blasts the dynamite was tied in a bundle about a wooden stick and the depth was determined very accurately. The depth given, in all instances, is the depth to the tops of loads. Where a number of sticks of dynamite were used in each hole, a metal tube was used to load through, sunk either with an auger or with a jet on a small hand pump. Figure 3 shows loading plans and table 2 gives depths and distances between loads. Figure 4 shows average excavations per foot of channel using various loading plans.

Experiments 1 to 6.

For purposes of discussion the Delaware experiments are divided into groups. In each group the intent was to develop some facts about the loading methods employed. In experiments 1 to 6 the purpose was to determine the efficiency of double-row loading (fig. 3,A).

Experiment 2 was a repetition of experiment 1 with the loads set nearer the surface. The small excavation per pound of explosives in experiment 1 was due to the load being set too deep for the spacings and quantity of dynamite used. A large amount of material was moved but not thrown out of the ditch. Experiment 2 gave much better results (see table 2).

Experiment 4 was a repetition of experiment 3 with the loads nearer the surface. It shows that experiment 3 had not been underloaded - that is, the depth and spacing were not too great for the load used because better results were obtained than in experiment 4 (see table 2).

The small excavation obtained per pound of dynamite, in experiment 5, was largely due to too much dynamite being used near the toe of the channel bank. The forces of the expanding gases were wasted in passing under and slightly heaving the channel side slopes. A single-row load may act the same way as a double-row load if it is too large for the ditch. Heavy loads set deep near the toe of the channel bank causes the sides to cave, give little excavation per pound of dynamite, and leave a very rough and unfinished appearance in the channel. Experiment 6 is a repetition of experiment 5 with the dynamite set at less depth.

Experiments 7 to 10.

In the six previous experiments two rows of loads were used. In experiments 7 to 10 the same quantities of dynamite were used per foot of channel, the same spacings were used, but the two rows of loads were combined in one so that each load was twice as large as in experiments 1 to 6 (fig. 3,B). These comparisons show single-row blasting to be far more efficient in sand than the double-row blasting of experiments 1 to 6. Too, these experiments show that about six sticks per hole (3 pounds) was most efficient, and that the efficiency decreased as the quantity of dynamite per load was greatly increased or decreased. In experiment 9 the ditch was overloaded and there was enough lateral expansion of gases to slightly heave the side slopes and cause waste through this lost work. Photo 6 shows the channel before and after blasting in experiment 8.

Experiment 11.

Cross-section loading was used in experiment 11 (fig. 3,C). In this test the loads are scattered even more than in double-row blasting. This blast gave better results than were obtained in double row experiments 1, 2, 4 and 5 and only slightly less favorable results than experiments 3 and 6 which seems to indicate that scattering the dynamite in numerous small loads was not alone responsible for the unsatisfactory results of the double-row loading, but that the spacing was perhaps too great. The loads were placed with the tops of the sticks 10 inches below the surface. Overspacing for the sizes of loads used in the double-row blasts caused a large amount of material to be lifted that was not thrown out of the channel. With this in mind, experiments were continued with shorter spacings and an effort made to obtain a more efficient loading.

Experiments 12 to 20.

Experiments 12 to 20 inclusive were made in series of threes, using single-row loads (fig. 3,B). In each series the quantity of dynamite and spacing remained constant; only the depth was varied. Results of these experiments fail to give very definite information on proper depths. They show that the depth should be increased with increases in loads; as would be expected. But small variations in depth do not appear to materially affect efficiencies in excavating sand (see table 2).

Experiment 21.

In experiment 21 the channel was wider than in other sections (approximately 16 feet bottom width), and it was desired to determine about what portion of the dynamite was wasted in heaving the berms in experiment 9. Here the channel was wide enough to prevent any heaving action under the side slopes. Implements were not available to set the charge to the 32-inch depth; however, in view of results in experiments 12 to 20, it appears that this 4-inch depth variation would not greatly influence results. In repeating experiment 9 in experiment 21, where

the channel bottom was as wide as the area lifted by the explosion, the dynamite used per cubic yard of excavation was decreased from 2.02 to 1.67 pounds, or 17 per cent. In other words, it seems that about 17 percent of the expanding gases were wasted in experiment 9 through heaving the side slopes. The efficiency of explosive was practically the same for 18 sticks at this depth as for 10 sticks at approximately this depth.

Experiments 22 to 26.

In experiments 12 to 20 the sizes of loads and the spacing remained constant while the depths of loads were varied. In experiments 22 to 26 the depth remained constant while the sizes of loads and spacings were varied. This was done to determine the best load size to use. It will be noted that the dynamite per foot of channel remained constant in these five experiments; that is, 2 sticks (1.0 pound) per foot of channel length. This series of tests showed increase in efficiency as the loads were concentrated; experiment 23 only was out of line with this trend.

After passing the 6-stick load, further increase in load size decreased the efficiency. The decrease in efficiency with increase in load size about 5 or 6 sticks is shown in experiments 12 to 20, inclusive. The loads for experiments 12 to 14 were 5 stick and the average explosive per cubic yard of excavation was 1.11 pounds. Seven sticks were used on experiments 15 to 17 and an average of 1.39 pounds of explosive were used per cubic yard of excavation. By using 9 stick loads in experiments 18 to 20 an average of 1.65 pounds of explosives were used for each cubic yard of excavation. Photo 7; shows views of channel before and after the blast, experiment 26. Photo 8 is a view of the blast and 9 shows end of blasted section, looking in opposite direction to view shown in photo 7.

Summary of results of loading in sand.

A review of table 2 shows that single-row loading with 5 to 7 sticks is the most efficient. The average of experiments 7, 12, 13, 14, 15, 16, 17, 25 and 26, shows 1.28 pounds of dynamite per cubic yard of excavation. The average for all 5-stick, single-row loads, experiments 12, 13, 14 and 25, is 1.20 pounds per cubic yard. The average for 6-stick, single-row loads, experiments 7 and 26, is 1.28 pounds per cubic yard. The average for all 7-stick, single-row loads, experiments 15, 16 and 17, is 1.39 pounds per cubic yard.

By loading five sticks 16 to 22 inches deep, single-row, at 3 foot spacing, from 1.0 to 1.15 pounds of dynamite will be required for each cubic yard of sand excavation. (See experiments 12 to 14.)

Seven stick loads, single-row, set at 22 to 24 inches deep, and on 3.0 foot centers, will require 1.25 to 1.40 pounds per cubic yard of sand. (See experiments 15 to 17).

Nine and 10-stick loads, single-row, set 16 to 32 inches deep and 3 to 6 feet apart will require from 1.60 to 1.75 pounds per cubic yard of sand excavation. (See experiments 8, 10, 18, 19 and 20).

Figure 4 shows about what top width of ditch may be expected from various sizes of loads used. To avoid waste of explosives, the top width of excavation that will result from the load used should not exceed the bottom width of channel before the blast is made.

Perhaps the most common fault in the past use of explosives for ditch cleaning work has been that of overloading - using too heavy charges - which increases excavation costs, leaves a rough channel of unfinished appearance, and causes caving of the side slopes.

Method of Detonating

There are a number of methods employed for detonating explosives in ditch blasting. The least expensive is propagation, if conditions are favorable. In this method, loads are set sufficiently close together so that when one of them is fired with an electric blasting cap the vibration (the propagating wave) fires the load next to it, the vibration of the second load fires the third, the third fires the fourth, etc. For successful propagation the soil must be thoroughly saturated. Ordinarily propagation is much better in heavy plastic soils than in light sandy soils. It was found that 40 percent nitro-glycerine dynamite did not propagate satisfactorily but that 50 per cent nitroglycerine dynamite did.

Where propagation can not be obtained, due either to methods of loading employed or soil conditions, electric blasting caps may be used.

In using electric blasting caps it is necessary to fasten each wire connection above the water to prevent short-circuiting. If water is flowing in the channel, the current may cause trouble by pulling down these connections. Most trouble of this kind will be experienced when the current carries debris which pulls down the wires and breaks connections. When using electric blasting caps they may be arranged either in parallel or series circuits. For small blasting machines a series circuit is usually necessary because these machines do not develop enough current to fire a large number of caps arranged in parallel.

Limitations in Use of Explosives

Where a section of a channel is to be repaired by widening the ditch, excavating from the side slopes with dynamite may prove costly. This type of work requires much scattering of explosives and thereby decreases dynamite efficiency. Only in construction or in taking material from the bottom of the ditch may explosives be used to best advantage. Proximity of buildings, bridges, telephone lines, or other property that may be damaged by the debris thrown by the blast will restrict the use of this method of excavation.

CLEANING CHANNELS WITH HAND LABOR

To determine the cost of hand labor in cleaning channels in Delaware, a crew of 11 men with a foreman experienced in handling ditch work was employed for about four weeks. The foreman was paid 40 cents per hour and the laborers 30 cents. The crew worked in three different sizes of channels, and all the material excavated was sand. Costs of excavation and of clearing briars and trees from the ditches were kept separate.

In a ditch having a top width of 25 to 30 feet, bottom width to 12 feet, and depth of 5.0 to 5.5 feet when completed, the cost of excavation was 82 cents per cubic yard, or $11.58 per rod. The average depth of cut was 2 feet (photo, 10,B). The cost of clearing was 42 cents per rod, and the total cost of the work $12 per rod.

In the same ditch, where the bottom width was 12.0 feet, the finished grade about 6.5 feet deep, the top width 28 to 33 feet, and the average depth of cut 1.4 feet, the cost of excavation was 84 cents per cubic yard or $9.60 per rod. The cost of clearing was $2.15 per rod, making a total of $11.75 per rod. In this second section there was a greater number of large trees cut than in the first section, but most of the difference in clearing cost was due to two very large trees, one partly covered with sand, in the ditch bottom. To get these out of the ditches by hand labor was expensive. Previously, most crews working on the ditches had not attempted to remove the trees.

In a third ditch there were no trees or briars, hence no clearing was required. There the top width was about 10 feet, bottom width 4.5 feet, the finished depth about 4.5 feet and the average depth of cut 1.1 feet. The cost of this work was 35 cents per cubic yard, or $1.53 per rod.

The last test of hand labor was in a small lateral with a top width of 12 feet, bottom width of 2.0 feet, finished depth of about 5.5 feet and average depth of cut was 0.7 foot. The cost of this excavation was 40 cents per cubic yard, or 37-1/4 cents per rod. No trees had to be removed but a very dense growth of briars had to be cleared away and this cost 19-1/2 cents per rod. The total cost of the work was 57 cents per rod.

The great variation in excavation costs can be ascribed to differences in width and depth of channels. In the two sections of large channel it was necessary for a man to take several steps with each shovelful of material from near the center of the ditch before he could throw it onto the bank. Because of the large amount of material taken out, it was necessary to handle this material a second time in throwing it back from the side slopes. In the smaller ditches no steps in the ditch and no second handling on the bank were necessary. The extra labor of carrying and second handling of the material and the impediments offered by large logs and trees in the ditch bottoms make hand excavation in large ditches too expensive to be practical.

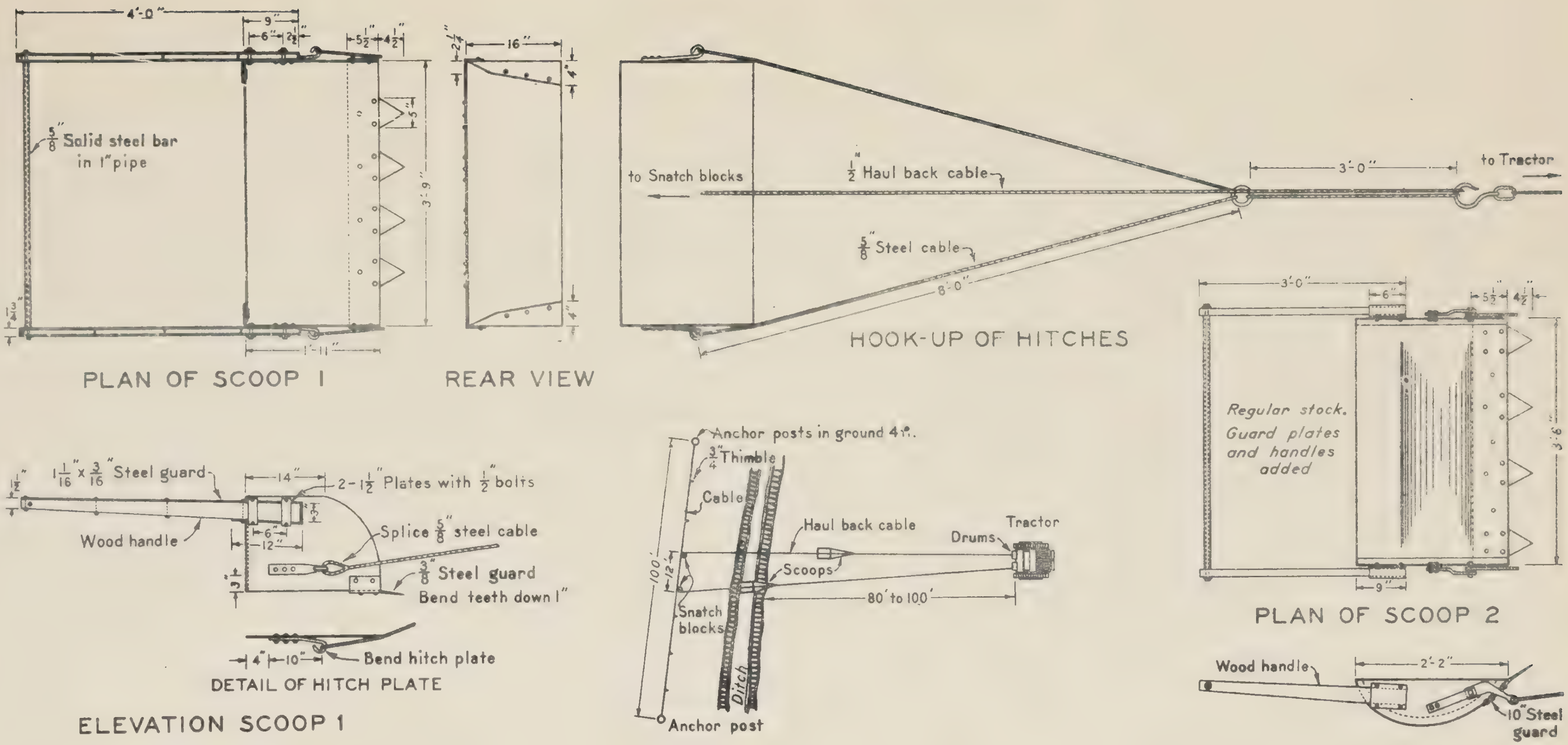


Fig. 5.—Details of scoops used with double-drum hoist

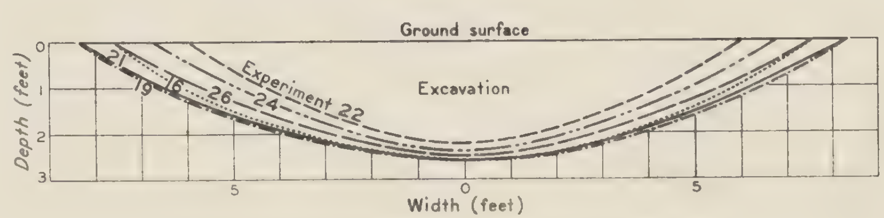


Fig. 4.—Approximate excavation obtained by various loading plans

CLEANING CHANNELS WITH TEAMS AND SCRAPERS

Two tests were made to determine the cost of ditch excavation with teams and scrapers. Although hand labor has been used almost exclusively for ditch work in Kent County, Delaware, some few ditches have been worked with teams and scrapers. For this work, inclines in the side slopes are cut about 300 feet apart. Teams enter at one incline, load the scrapers in the ditch, and pull out at the next incline. Five drivers with teams and scrapers were hired at 50 cents per hour each. Two men to load the scrapers in the ditch were paid 25 cents per hour each, and the foreman was paid 40 cents. No clearing of brush or trees was necessary for this work.

The cost of cutting inclines and excavating material in one test was 62 cents per cubic yard, or $4.56 per rod. The top width of this ditch was about 20 feet, and the bottom width 10 feet; the cut was about 1.0 foot, and the finished channel was about 5.5 feet deep. The inclines for the second test, in the same channel, had been prepared before the work was begun. The cost of excavating was 56 cents per cubic yard.

Excavated material in both sections was sand. Scrapers were usually loaded with 2 to 3 times as much sand as remained on them when they reached the top of the incline. Sliding them through the water 30 to 40 feet usually washed off 1/2 to 2/3 of the original load. While this decreased the rate of useful work, it is probably true that teams worked much faster in this sand than would be possible in any other soil. In many of the muck or plastic soils teams could not be used at all. Team and scraper work, while more efficient than hand labor, is a costly method of ditch repair.

CLEANING CHANNELS WITH DOUBLE-DRUM HOIST WITH SCOOPS

Many farmers have tractors, and an experiment was conducted to determine what might be accomplished with tractor power in ditch work. A tractor and drum-hoist outfit was arranged to haul scoops back and forth across the channel. Tests were made with a number of scoops in the Delaware work, and the ones finally selected are those shown in Figure 5. For light excavation and in small ditches scoop No. 2 was found most satisfactory, but in heavy cuts scoop No. 1 was better. The hoist had three speeds forward and one reverse. The average speed of the drag cable was about 125 feet per minute. The slack in the hitch between the scoop and the main drag cable was 10 to 11 feet. (Fig. 5.) This gave the men 10 to 12 seconds to place each scoop. By working scoops off to the sides of the drag cable, a section of ditch about 30 feet long was usually cleaned at each setup.

A 35-horsepower, crawler-type tractor with a double-drum hoist was used to operate the scoops (fig. 5). A magazine and tool box were mounted on skid runners and hauled about with the tractor. Several large snatch blocks were carried for use in removing large logs and trees from the bottom of the ditches. Dynamite was available to blow stumps and to blast the ditch where this could be done to good advantage.

Explosives were used for excavations where 2 feet or more was to be taken from the bottom of the ditch and none was to be taken from the side slopes, or where gravel was encountered (which was very infrequently), or where a cut-off was to be made to eliminate a sharp curve.

Five men were required to operate this outfit. One drove the tractor and acted as foreman, two men in the ditch loaded the scoops, and two men on the bank dumped the scoops. (One of the men on the bank acted as subforeman). The loaders set the anchor posts and moved the snatch blocks forward; the dumpers helped to align the tractor as it was moved forward, brought up the scoops, and cared for all tools. Laborers were paid 30 cents per hour, the foreman 50 cents, and the sub-foreman 35 cents. Gasoline, oil, and depreciation of equipment were figured at $7.00 per day.

In repairing 4.77 miles of ditch such as shown in photo 11 the average cost was $2.75 per rod. This cost includes all explosives as well as tractors work. In a second ditch the cost was $2.32 per rod. In a third it was $1.18. The cost per cubic yard remained about constant on all this work - 24 to 26 cents. The costs per rod include cutting trees and brush and hauling fallen trees and logs from the ditches. This outfit, like the teams and scrapers, works much better in sand than could be expected of it in heavy, sticky soils.

Through the use of farm tractors a very good job of maintenance can be accomplished at reasonably low cost if suitable hoist attachments are available. Hauling scoops and logs from the ditches is heavy work and the hoist must be mounted low to prevent tilting up the front of the tractor. Double drums set end to end and low on the tractor are much better for this job than those set high with one drum above the other. At present, hoist prices are too high to make such an investment profitable for the averagefarmer. A hoist of the type used in this work sells for about $1,500 which is too great an investment for a machine that will be used only a month or two each year.

CLEANING CHANNELS WITH DRAGLINE EXCAVATORS

Two tests were made with dragline excavators to determine costs of reconstucting a number of large channels in the county. A 1/2-yard excavator was rented for $33 per day and a 3/4 yard machine for $36 per day, including operators, gasoline, and oil. Both the machines were equipped with narrow-tread crawlers, constructed for gravel pit or other dry land work. Due to the swampy conditions the 3/4-yard dredge was operated on mats, which added to the excavation cost.

The 1/2-yard machine made a cut about 16 feet wide and 3 to 4 feet deep, excavating about 2-1/2 cubic yards per running foot. The cost of this was 9 cents per cubic yard or $3.70 per rod. Removing trees to permit the machine to operate was accomplished with a tractor and a crew of four men at a cost of 87 cents per rod, making a total for excavating and clearing of $4.57 per rod.

With the 3/4-yard machine, making a cut about 28 feet wide and 5 feet deep, excavating about 5 cubic yards in each running foot of channel (see photo 12) the cost was 8.2 cents per cubic yard or $6.80 per rod. Removing trees to permit machine operation cost $1.35, making a total of $8.15 per rod. The trees were cut by hand, stumps were blasted, and the dragline was used to throw the trees clear of the channel section.

In reconstruction work where excavation is continuous and heavy throughout the length of the channel, use of a dragline is very economical. However, where only intermittent bars and debris at widely separated intervals are to be excavated, large machines are not practical due to high moving costs.

PREVENTION OF CHANNEL AND BANK EROSION

Kent County, Delaware, has a flat to gently undulating topography and only small amounts of silt are carried into the ditches from the fields. With properly designed channels and a little care to prevent obstruction by vegetation or logs, practically all the silt delivered to the channels could be transported by the stream. A large part of the silt which deposits at the critical sections (sections where velocity is retarded) comes from channel erosion. Measures should be taken to stabilize channel sections where such erosion occurs. These occur where concentrated flow has an overfall into the main channel, and at abrupt bends or changes in the direction of flow.

Most of the Kent County lowlands have a black clay loam top soil 2 to 3 1/2 feet deep, which is not easily eroded. Under this is a fine sand that is highly erosible. Where overfalls extend down into the sand, erosion is very active. Where bends or curves occur and the bottom of the ditch is below the black top soil, scouring or erosion at the toe of the bank causes the latter to cave at the outside of the curve.

Three different methods are employed to stop erosion at the overfalls. Log check dams are employed as shown Photo 13. These dams were constructed to have about 5 inches of overfall and were spaced 6 to 10 feet apart. Bottoms of dams were extended 14 to 18 inches below the bottoms of the channels, but 8 to 12 inches would have been sufficient. Stakes 18 inches long were driven into the channel bottom between overfalls, staggered, on 12-inch centers, and left protruding 6 inches above the channel bottom. These were to serve two purposes - first, to check the velocity of the water and thus avoid the necessity for aprons; and second, to aid the deposition of silt, leaves, and other debris, which will eventually cover the dam. Vegetation then will grow in the ditch bottom and replace the dams. These were used on small overfalls of about 2 1/2 feet or less and where small quantities of water entered. A number of overfalls about 4 feet high were treated by this method at an average cost of $10 each for labor. There was no material cost.

A metal pipe was used to stop erosion at a 5 1/2 foot overfall as shown on photo 14. The bottom of this small lateral was above high water stage of the main channel and the pipe could be projected into the main channel without danger of it catching floating debris or being destroyed by logs or other heavy objects carried by the current. The cost of this job was $20 for material and labor on contract work.

Another lateral drain showing active erosion was not above high water stage, so a pipe could not be projected into the main channel. The overfall and size of watershed made vegetative control very uncertain, therefore the reinforced concrete check dam shown in photo 15 was employed. Four of these were installed by contract, at an average cost of $60 each.

To check erosion on sharp curves the alignments were straightened. In a number of instances, outside banks on curves were revetted with brush. After stabilizing the channel sections as much as possible and reducing silt caused by channel erosion, an effort was made to eliminate all obstructions that caused deposition of silt and lodgment of debris. Elimination of abrupt curves helped considerably. The practice of building fences across ditches and setting posts on the side slopes or in the bottoms of the channels provided numerous additional traps for catching logs and other debris, which often formed dams that backed a 2-foot head of water. These were removed and replaced with suspended gates as shown in photo 16. Each gate was suspended from a log that spanned the ditch 3 to 4 feet above high water. The gate is lifted by the current as the stage rises.

CONTROL OF VEGETATION

Experiments conducted by engineers of the Bureau of Agricultural Engineering show that velocities may be reduced one-third or more by vegetation in the channel. Dense growths of vegetation always cause silt deposits if the current carries any appreciable silt burden.

In Kent County a dense growth of briars flourishes along the side slopes of many of the channels. This vegetation greatly retards flow, especially during the growing season. Some farmers cut and burn these briars every fall, but by next mid-June they have again attained a growth sufficient to stop flow almost completely in the small ditches. From mid-June until late fall, when the briars are again cut and burned, all silt and debris carried into the channels are deposited, due to this growth obstructing the velocity, and the fields are poorly drained during a large part of the growing season.

As an experiment in eradicating a growth of greenbriars, a spray of sodium chlorate was used on a channel section several miles long. This solution consisted of 1 pound of sodium chlorate to 1 gallon of water, and the first spraying, using 3 gallons per square rod, was done during the blooming season in June. The following spring the briars were sprayed again, with 1 gallon of solution per square rod about June 1. This channel was inspected a year after the second spraying and practically all of the briars had been killed.

About 2 square rods per linear rod of channel were sprayed. The chlorate cost 7 cents per pound and labor and materials for the two sprayings cost 62 cents per rod. A power-driven sprayer mounted on a truck photo 17, was used for both applications. These briars could be cut and burned for about 25 cents per linear rod of channel. Although spraying is more costly than cutting and burning for one season, it is much less costly over a period of years and it has the advantage of providing an open channel for good drainage during the entire year. By keeping channels open throughout the year, silt deposits and consequently excavation costs are reduced.

This chlorate solution does not sterilize the soil but only kills the vegetation on which it is sprayed. Dense growths of grass and annual weeds now occupy the banks where the briars were killed with the chlorate spray. The grass and annual weeds offer little obstruction to flow. Special precautions should be observed in handling sodium chlorate due to its inflammability. The chlorate is not poisonous to livestock but manufacturers advise that livestock be not permitted to eat large quantities of vegetation recently sprayed because they may develop an appetite for this salted food, resulting in overeating.

SUMMARY AND CONCLUSIONS

The costs of maintaining drainage channels vary considerably depending upon the methods used, existing channel conditions, types of soils, wages of labor, and topography of the watershed. Care should be used in applying the data obtained in these investigations to localities having different conditions. Additional investigations are needed to determine the most economical methods of maintaining drainage channels in other regions.

The results of these experiments indicate that dynamite should prove very useful in carrying out a systematic maintenance program. For small construction jobs, the maintenance or repair of channels by cleaning out widely separated bars, or constructing cut-offs for relocations, the use of dynamite is usually economical. This method requires no large investment in equipment, and explosives are always available. Dynamite offers a quick and economical means of removing newly formed channel obstructions before large silt deposits are formed and heavy growth of vegetation occurs.

The method of loading has great influence on the unit cost of excavation with dynamite. Concentrated loads generally give best results. On sizable jobs it is advisable to determine by experiment the most economical method of loading.

Dynamite was found to be more efficient in clay or plastic soils than in sand. In the Ohio experiments in clay, unit costs as low as 10 and 11 cents per cubic yard were obtained by using a single row of charges of 5 sticks each, 10 inches depth, 4 feet apart.

In the Delaware experiments in sand, the lowest unit cost was 16 cents per cubic yard of excavation, obtained by a single row of charges of 5 sticks at 16 inches depth spaced 3 feet apart. The cost for single-row charges of 5 to 7 sticks at depths of 10 to 28 inches and spaced 2 1/2 to 3 feet apart varied from 16 to 23 cents per cubic yard. When less efficient methods of loading were used, the cost ranged up to 93 cents per cubic yard. With proper loading methods, ditch blasting can be accomplished at reasonable cost in practically any sand. Unit costs mentioned above were based on dynamite at 15 cents per pound.

The use of dynamite was not found to be economical in widening ditches or in excavating from the side slopes, nor was it usually economical for deep, heavy cuts involving large yardage. Each job should be carefully analyzed to determine whether dynamite, excavating equipment, or some other method is most economical.

The cheapest method for detonating explosives is by propagation. This method is much more satisfactory in clay than in sand soils. When using electric caps in water, short circuits occur, particularly in flowing water, and cause misfires. Best results from the use of dynamite are obtained when the soil is well saturated.

Excavating by use of dynamite has the advantage of spreading dirt over adjacent fields instead of concentrating it in spoil banks as is usual when excavating machinery is used Disadvantages are that it cannot be used near buildings, bridges or telephone and power lines which might be damaged by blasting.

Both hand labor and team-and-scraper work are too expensive for ditching work of any magnitude, where the removal of trees and logs from the channels requires a large amount of power. On small ditches hand labor may be practicable if farmers can do their own work or use farm hands at little or no additional cash outlay. However, where farmers pay a salary for labor to clean channels either by hand or with teams and scrapers, the cost is usually excessive and generally the work accomplished is inferior. In the case of hand labor, it is almost impossible to get all material thrown clear of the channels so that a large part of it will not be washed back into the ditch. This is particularly true when working on large ditches. It is always difficult, also, to obtain a good grade because there is a tendency to pass over materials not easily worked with hand shovels.

Tractors with hoists and scoops would be practical for light construction and maintenance work if suitable hoists were available at reasonable prices. Excavation costs with this type of outfit averaged 24 to 26 cents per cubic yard. At the present time good hoists are too costly for individual farmers to purchase solely for ditch work.

Excavating with dragline or floating dredge is no doubt the most economical means of removing sizable yardage under favorable conditions. Where ditches have silted up to the extent that they average only 2 or 3 feet deep, and it is necessary to excavate several feet in depth to bring them to proper grades, it is usually advisable to estimate yardage and secure bids on the cost of doing the job by machine. The unit costs of excavating with the machinery used in the experimental work in Delaware were 8 and 9 cents per cubic yard.

Poisons give promise of controlling some plant growth on ditches and of lessening the annual clearing required.

A maintenance program should be more than a system of clearing vegetation and excavating. Provision should be made to control and reduce silting and prevent erosion of banks.

Legends for Photographs

Photo 1.- A, Before blasting; B, after blasting using cross section loading.

Photo 2.- Appearance of a ditch after blasting using single-stick, single-row loading.

Photo 3.- A, Before blasting; B, after blasting using half-stick, single-row loading.

Photo 4.- A, End view; B, side view of the blast in experiment 13 in which half-stick loads were used.

Photo 5.- A, Before blasting; B, after blasting with 5-stick concentrated loading.

Photo 6.- A, Before blasting; B, after blasting using single-row, 10-stick loading.

Photo 7.- A, Before blasting, B, after blasting, using single-row, 6-stick loading spaced 3 feet apart.

Photo 8.- Blast of ditch shown in photo 7.

Photo 9.- End of blasted section looking in the opposite direction from that in photo 7.

Photo 10.- A, Before cleaning; B, after cleaning, using hand labor.

Photo 11.- A, Before cleaning; B, after cleaning, using double-drum hoist with scoops.

Photo 12.- A, Cleaning ditch with drag-line excavator; B, appearance of ditch after cleaning.

Photo 13.- Log check dams used to check erosion in ditch. Stakes are driven in bottom of ditch between dams to prevent scour.

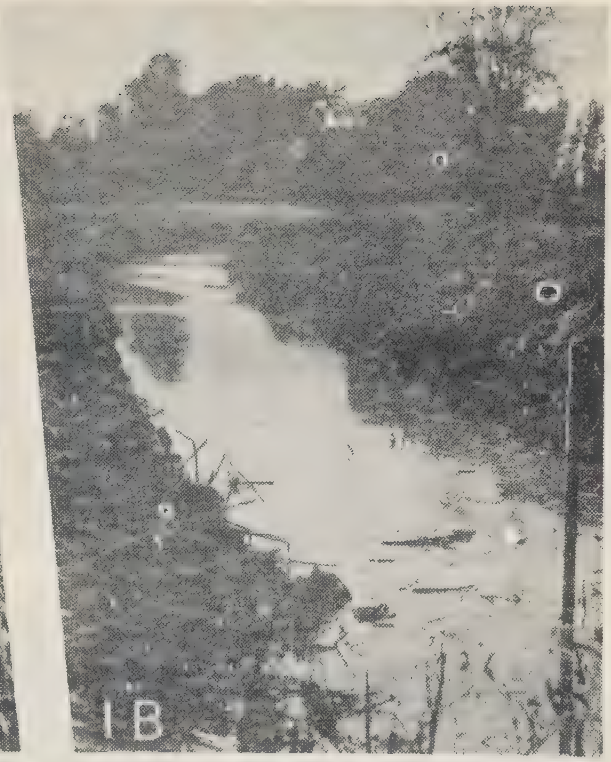
Photo 14.- Corrugated metal pipe projecting into main ditch to avoid erosion by a small lateral ditch.

Photo 15.- Reinforced concrete drop installed at the outlet of a small lateral ditch.

Photo 16.- Suspended gate across drainage ditch.

Photo 17.- Spraying sodium chlorate to kill briars in a drainage ditch using a mounted power-driven outfit.


1A


1B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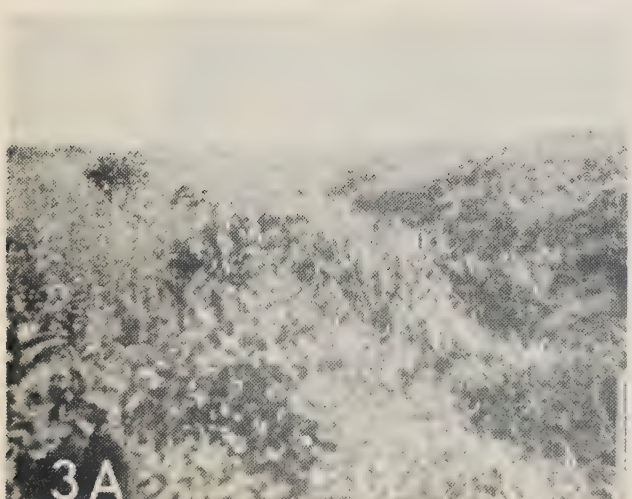
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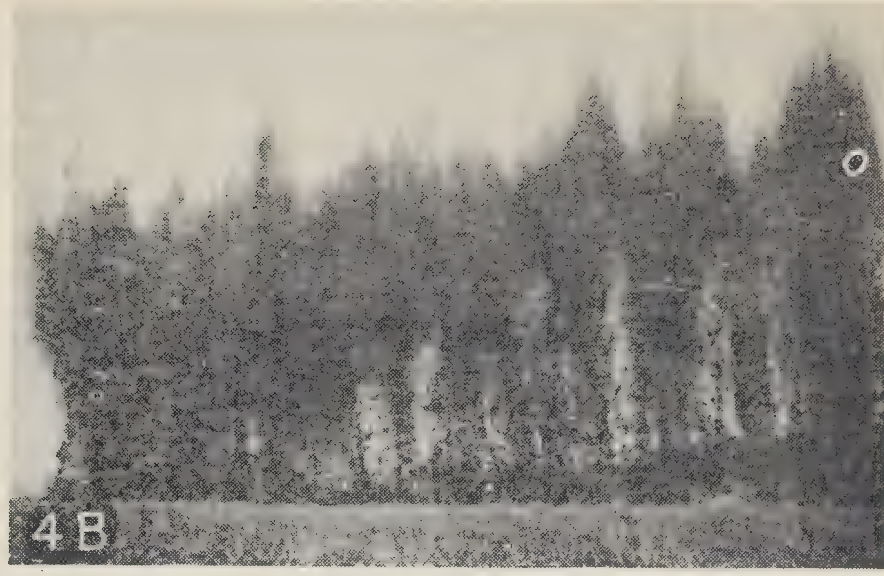
3B


4A


4B


5A


5B


6A


6B


7A


7B

8

9

10 A

10 B


11A


11B

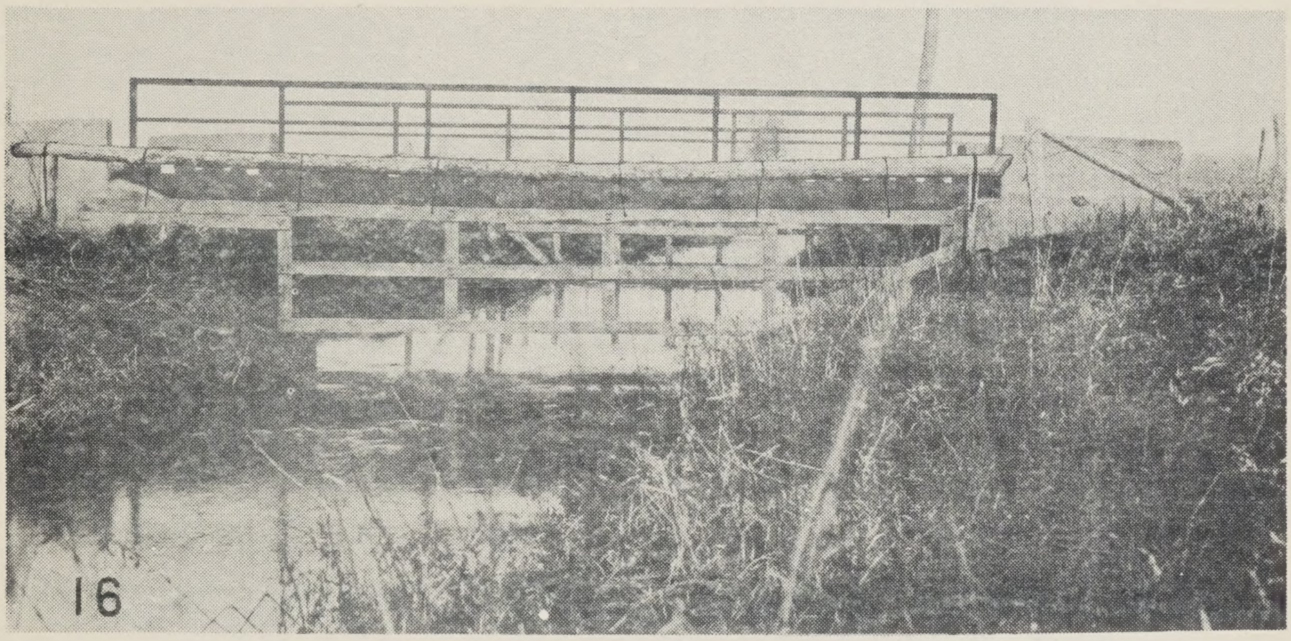

12A


12B

13

14

15



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